The Current Space Debris Situation

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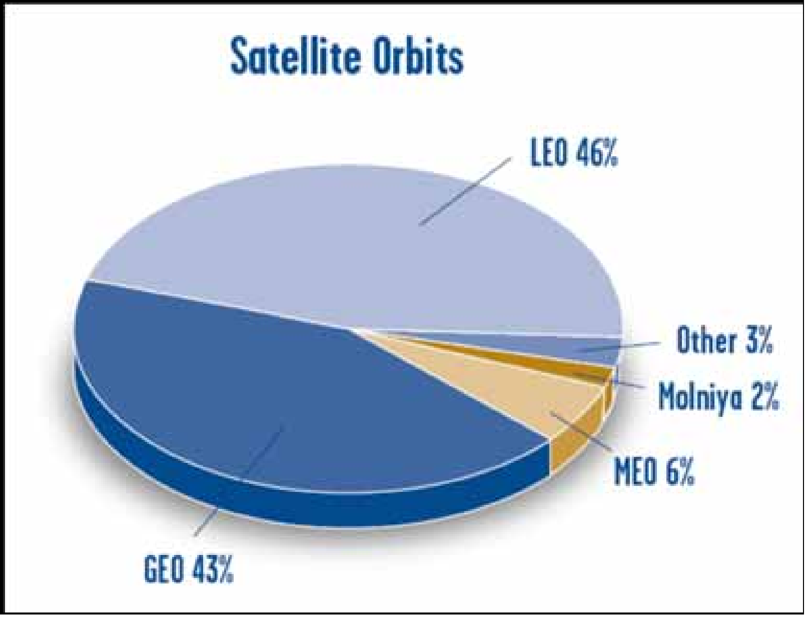
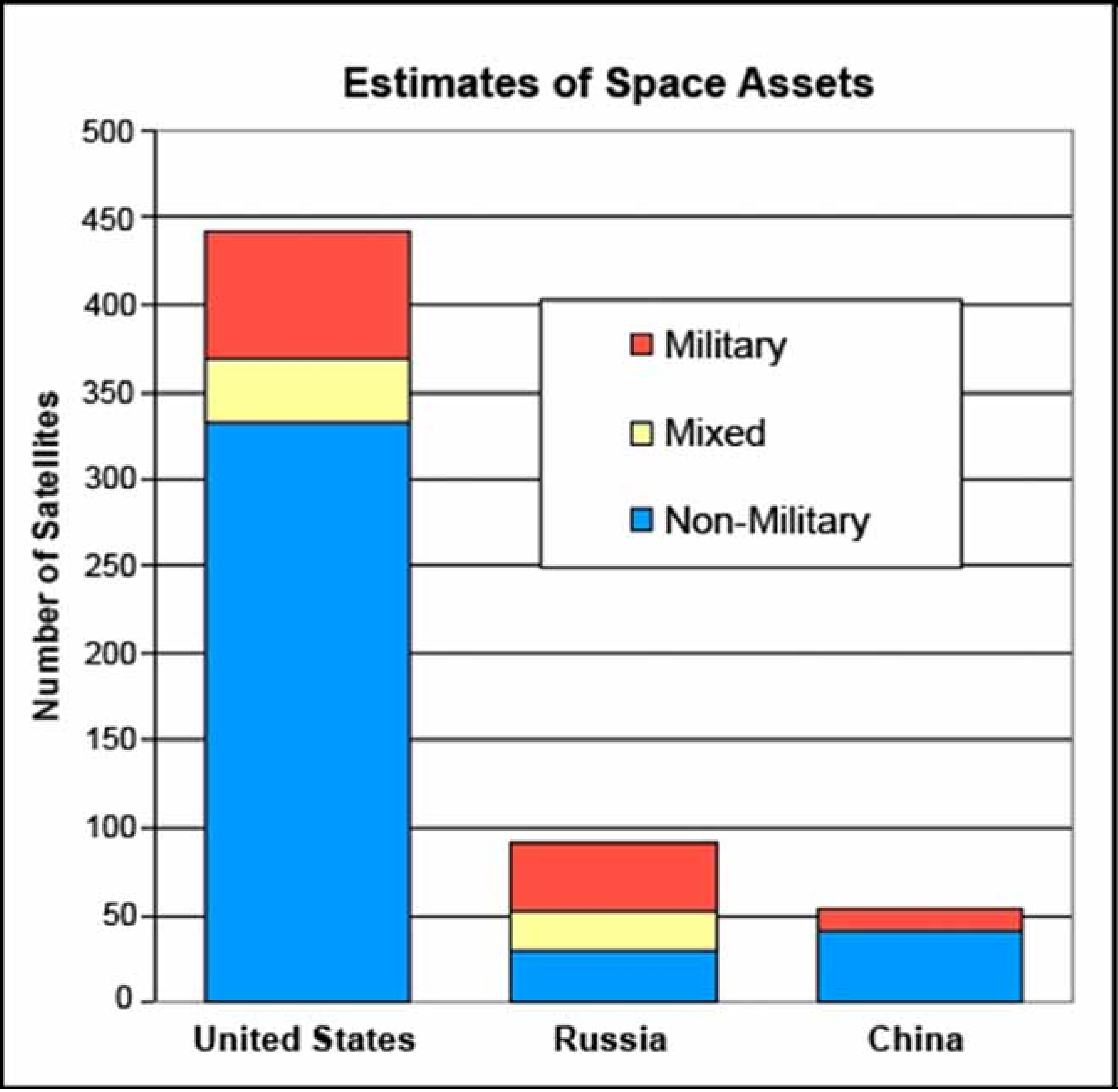
What's in Space Today?

- Currently ~ 950 operational satellites
- 3 areas of space contain 95% of operational satellites:
  - **Low earth orbit (LEO)**: 300-2,000 km altitude
    - 1.5 - 3 hour period
    - 7 - 8 km/s orbital speed
  - **Semi-synchronous (MEO)**: 20,000 km altitude
    - Navigation satellites (eg, GPS)
    - 12 hour period
    - 4 km/s orbital speed
  - **Geosynchronous (GEO)**: 36,000 km alt.
    - Communication/broadcast satellites
    - 24 hour period
    - 3 km/s orbital speed



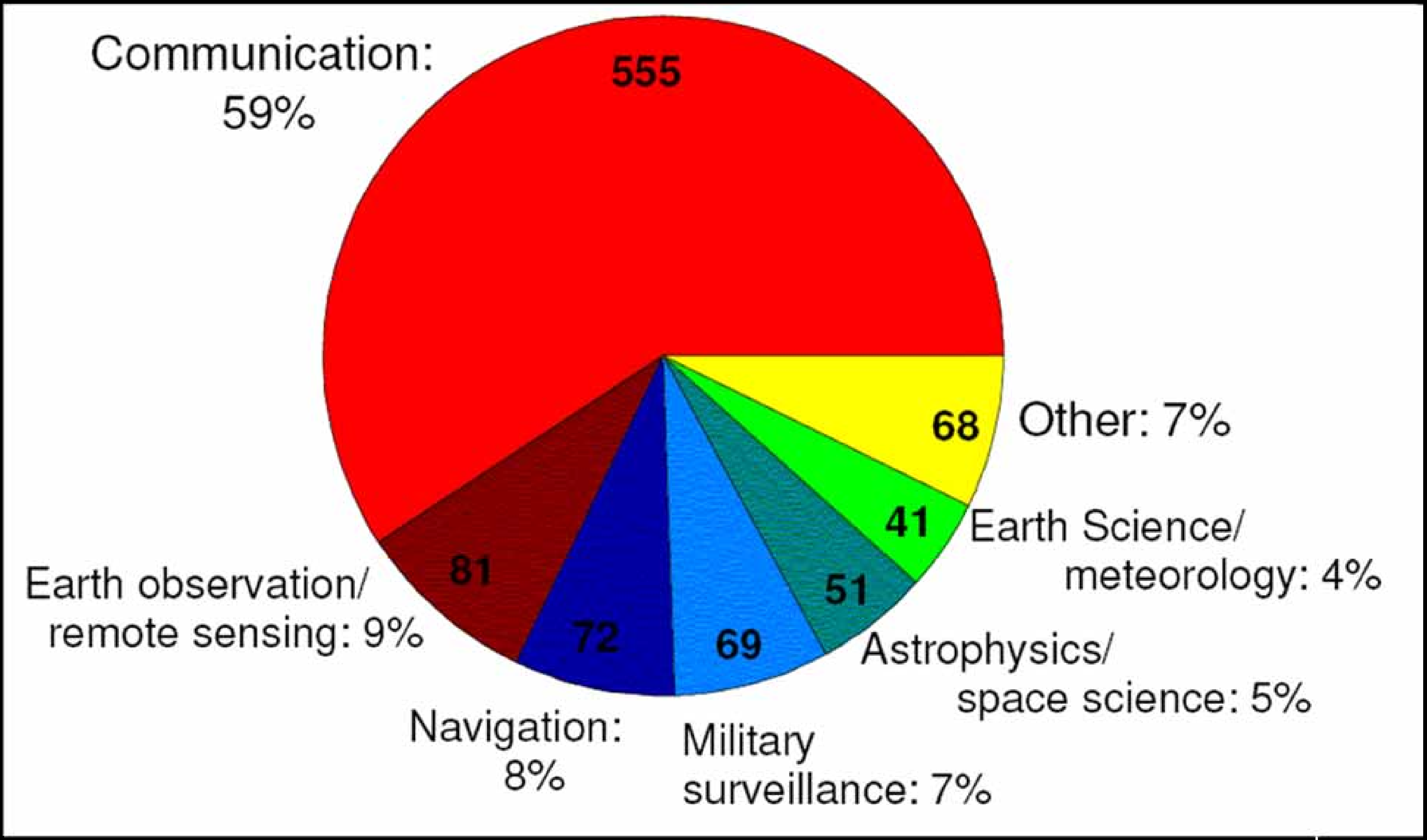
Current Active Satellites



Rest of World =

348 active satellites

What Are Current Satellites Used For?



"Total Debris" vs "Cataloged Debris"

- The U.S. military tracks objects in space with radar and optical sensors in the Space Surveillance Network (SSN)
  - Can track objects in LEO larger than 5-10 cm in size
  - Can track objects in GEO larger than ~1 m in size

- U.S. military keeps a <u>Catalog</u> of objects—currently >15,000 objects

- To be in the Catalog:
  - the object must be tracked by SSN
  - the object's origin (La must be known

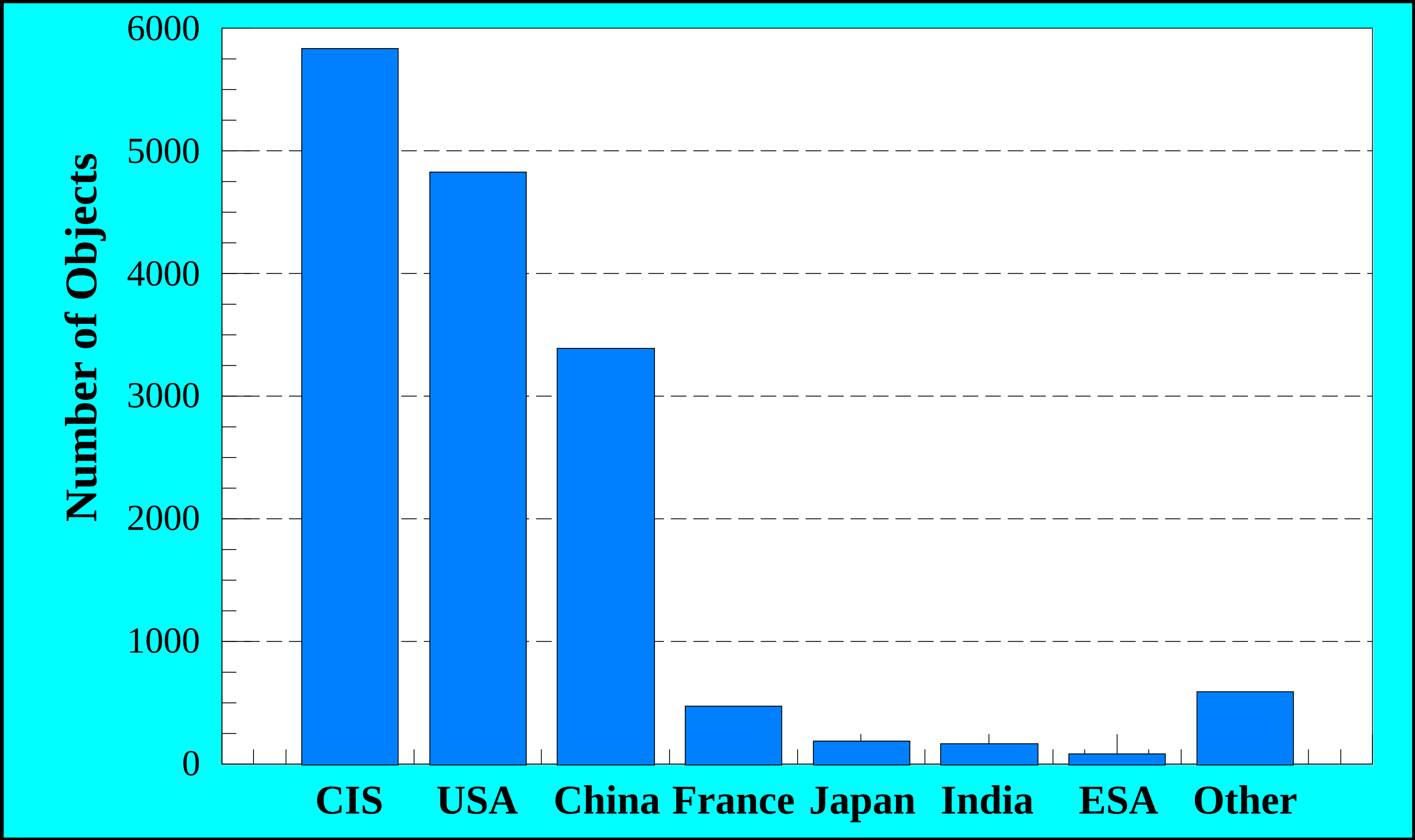
➔ the total amount of debris is much larger than the number of objects in the catalog

Current Estimates of Total Debris in Orbit

	1 to 10 cm	**> 10 cm**
LEO debris	400,000	14,000
Debris at all altitudes	750,000	24,000

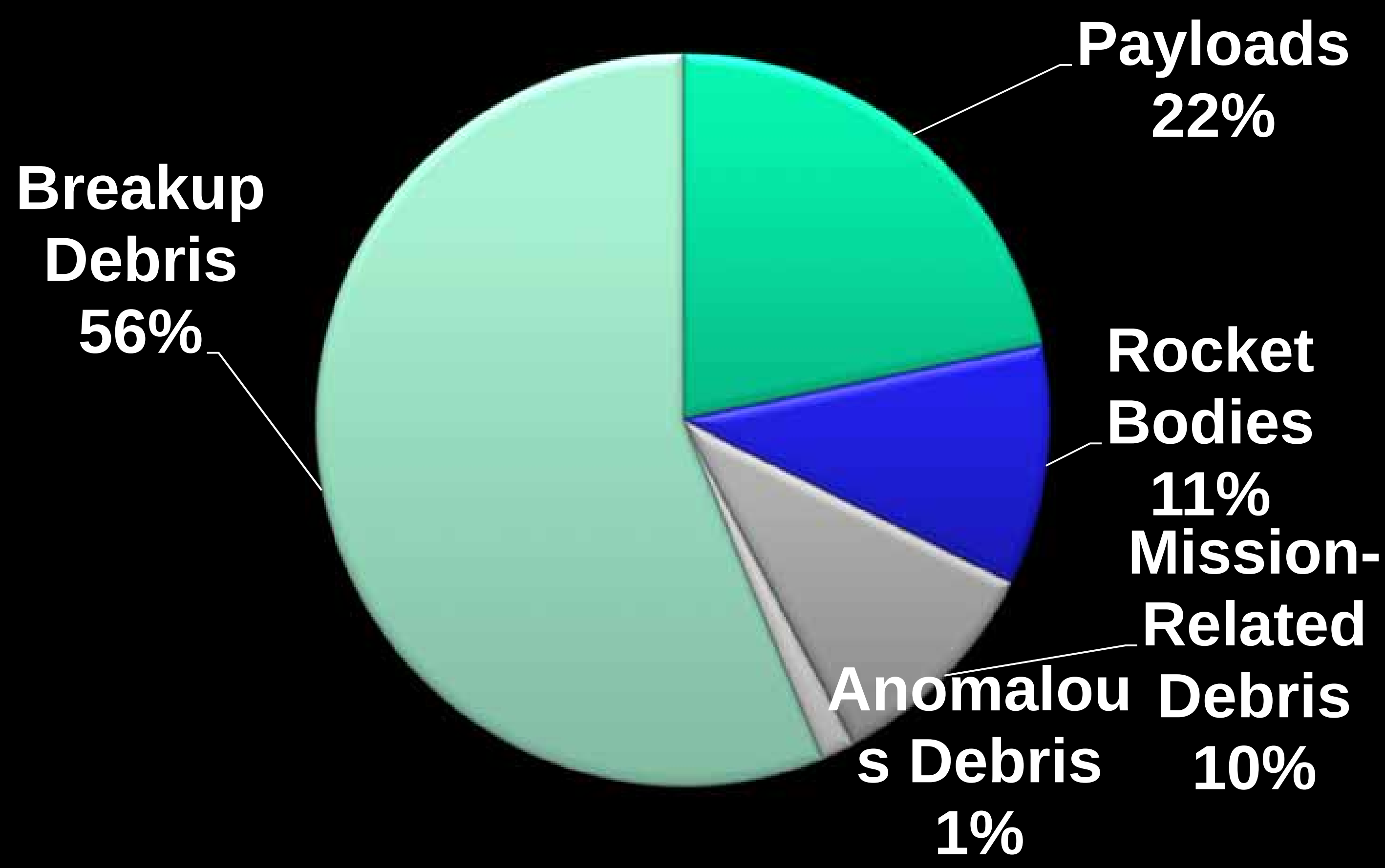
Roughly half of all debris of this size is in Low Earth Orbit
(or LEO, which is < 2,000 km altitude)

Number of Satellites + Debris by Country



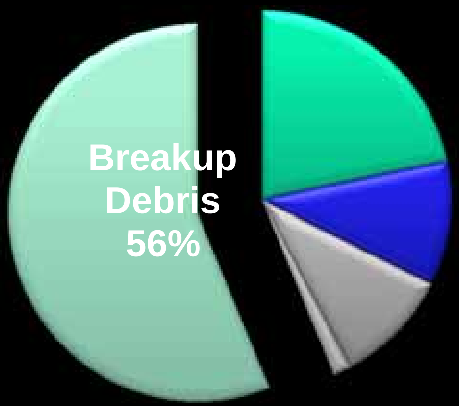
Data from NASA Orbital Debris Quarterly News, July 2010

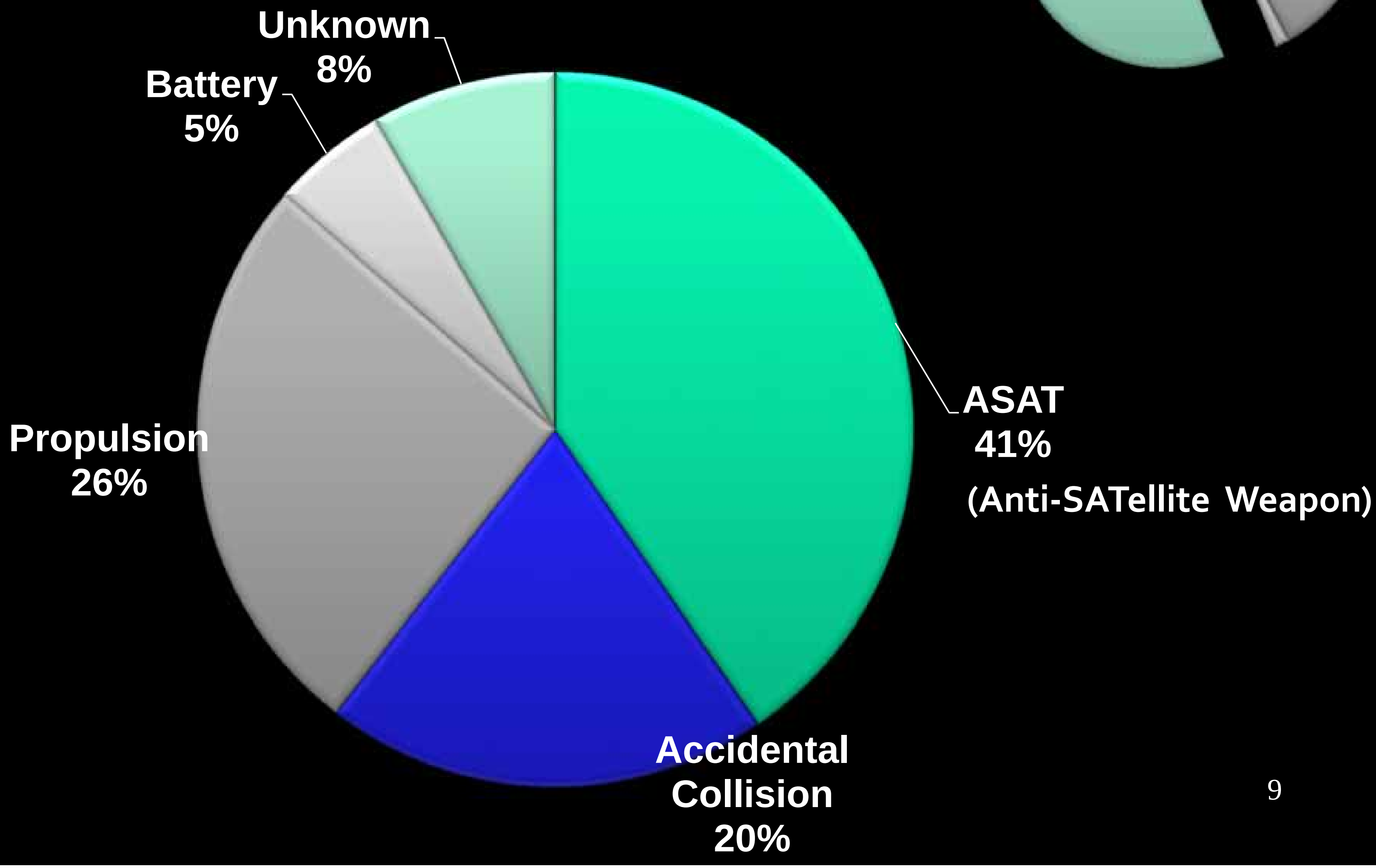
Origin of Cataloged Objects in Space



Payloads and Rocket Bodies make up 99% of the mass of all objects in space. These are a source of future debris

Breakup Debris

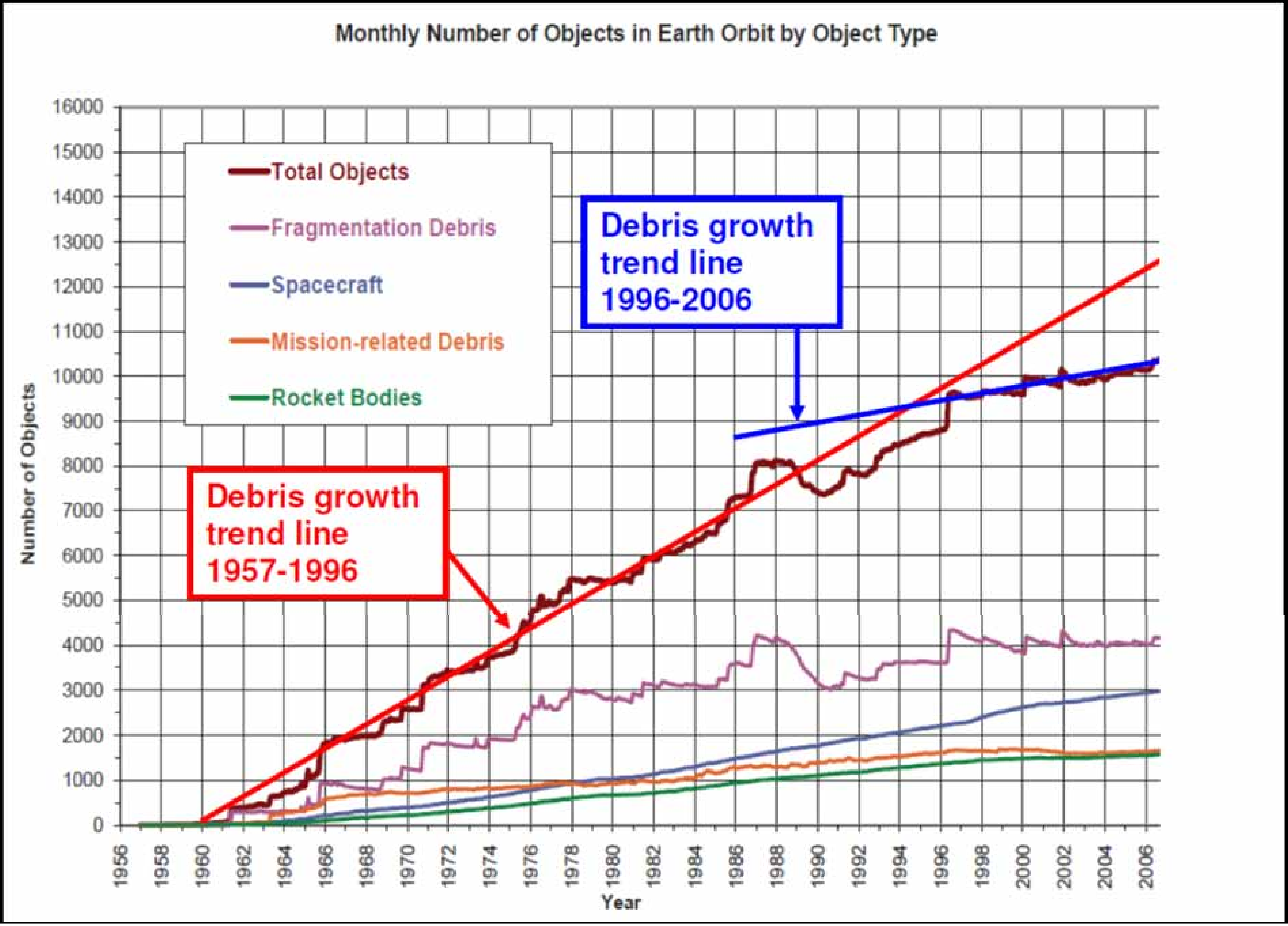




Top 10 Debris Events (as of May 2010)

Name	Year	Altitude	Cataloged Debris	Debris in Orbit	Cause
Fengyun-1C	2007	850 km	2841	2,756	Intentional collision
Cosmos 2251	2009	790 km	1267	1,215	Accidental collision
Briz-M RB	2007	500x15,000	85	> 1,000	Accidental explosion?
STEP 2 RB	1996	625 km	713	63	Accidental explosion
Iridium 33	2009	790 km	521	498	Accidental collision
Cosmos 2421	2008	410 km	509	18	Unknown
SPOT 1 RB	1986	805 km	492	33	Accidental explosion
OV 2-1/LCS 2 RB	1965	740 km	473	36	Accidental explosion
Nimbus 4 RB	1970	1075 km	374	248	Accidental explosion
TES RB	2001	670 km	370	116	Accidental explosion

Historical Growth of Space Debris Through 2006



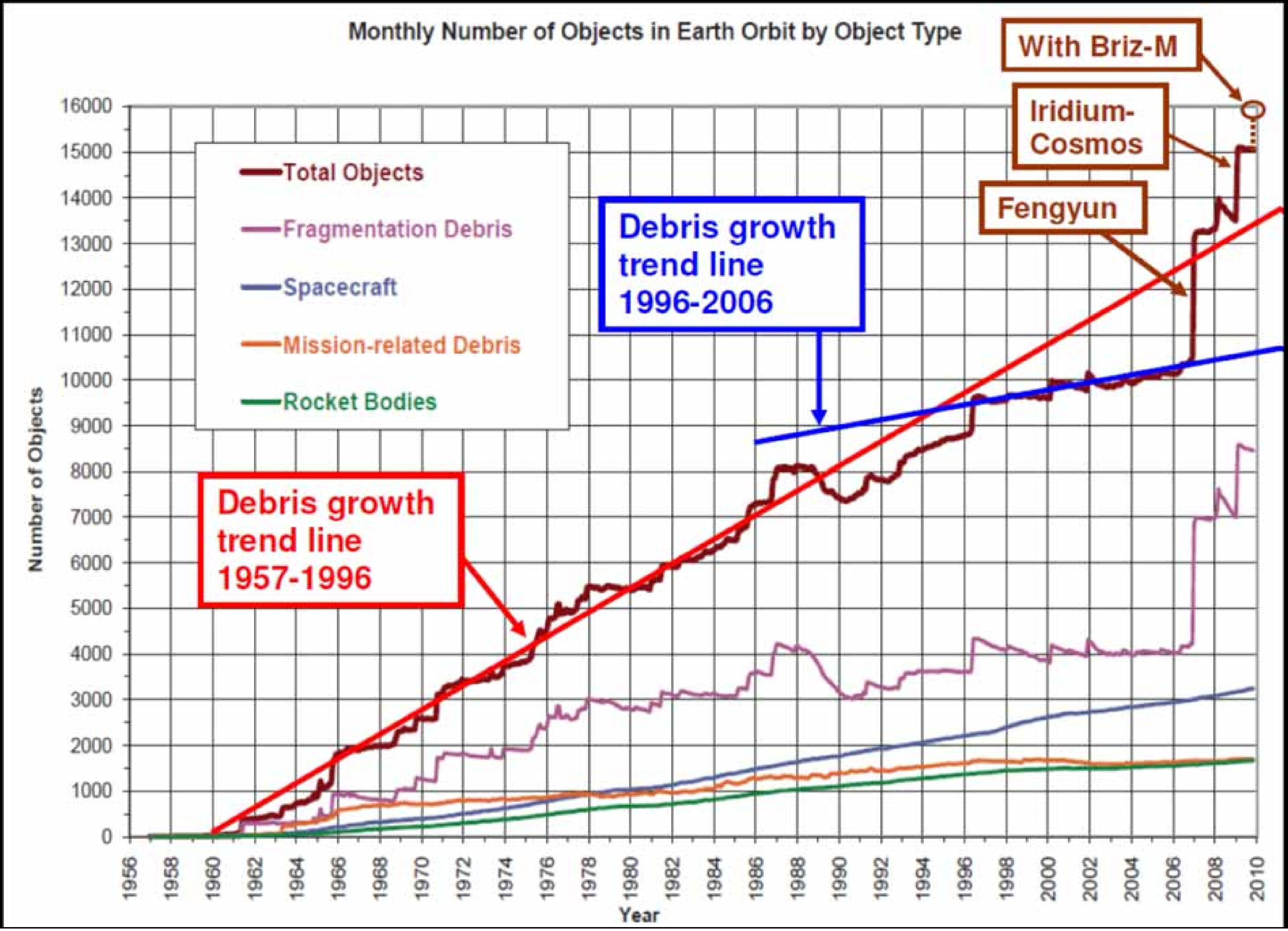
Through 1996, U.S. and Soviets/CIS added an average of 100-120 objects/year to the catalog.

	Dec. 1996	Dec. 2006	Increase
CIS	3836	4277	11.5%
United States	3990	4152	4.1%
China	112	391	
Total for All Countries	8507	9949	17%

For the decade 1996-2006:

- CIS added average of 44 objects/year
- U.S. added average of 16 objects/year

Historical Growth of Space Debris Through 2010



Categories of LEO Debris

Physical Size	Comments	Potential Risk to Satellites
> 10 cm	-Can be tracked -No effective shielding	Complete destruction
1-10 cm	-Larger objects in this range may be tracked -No effective shielding	Severe damage or complete destruction
< 1cm	-Cannot be tracked -Effective shielding exists	Damage

Hypervelocity Collision

Aluminum sphere: 1.2 cm diameter at a velocity of
Aluminum block: 18 cm diameter and 8.2 cm thick
Impact speed: 6.8 km/s
Creates a crater and rear wall spallation

Debris Estimates from the Breakup of a Single Large Satellite

	1 to 10 cm	**> 10 cm**
Current LEO debris	370,000	14,000
Debris from 10-ton satellite breakup	250,000 - 750,000	5,000 - 15,000

➔ **The destruction of a *single* 10-ton satellite could double or triple the amount of large debris in LEO**

Numbers based on NASA Standard Breakup Model and Fengyun breakup

Debris Evolution from ASAT Attack

Figure 2. Cloud of debris of size greater than 10 cm after 15 minutes.

Figure 3. Debris cloud after 10 days.

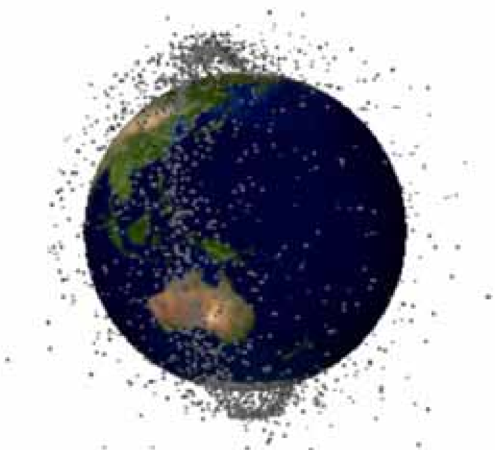


Figure 4: Debris cloud after 6 months.

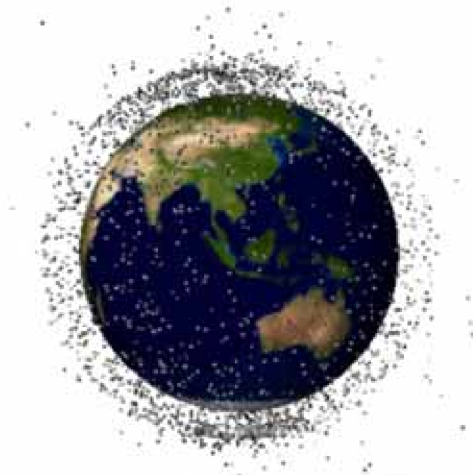
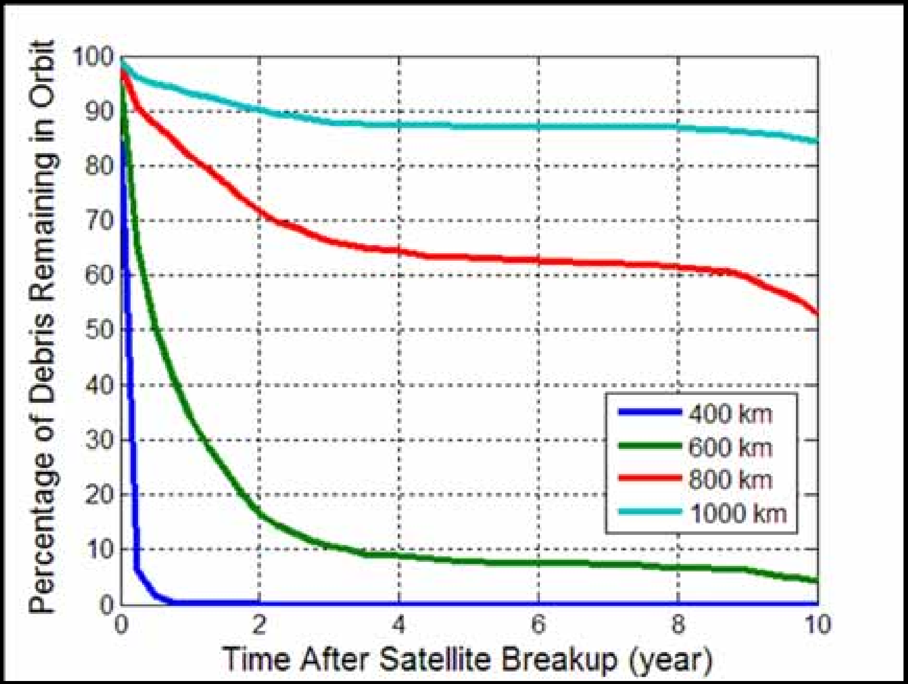


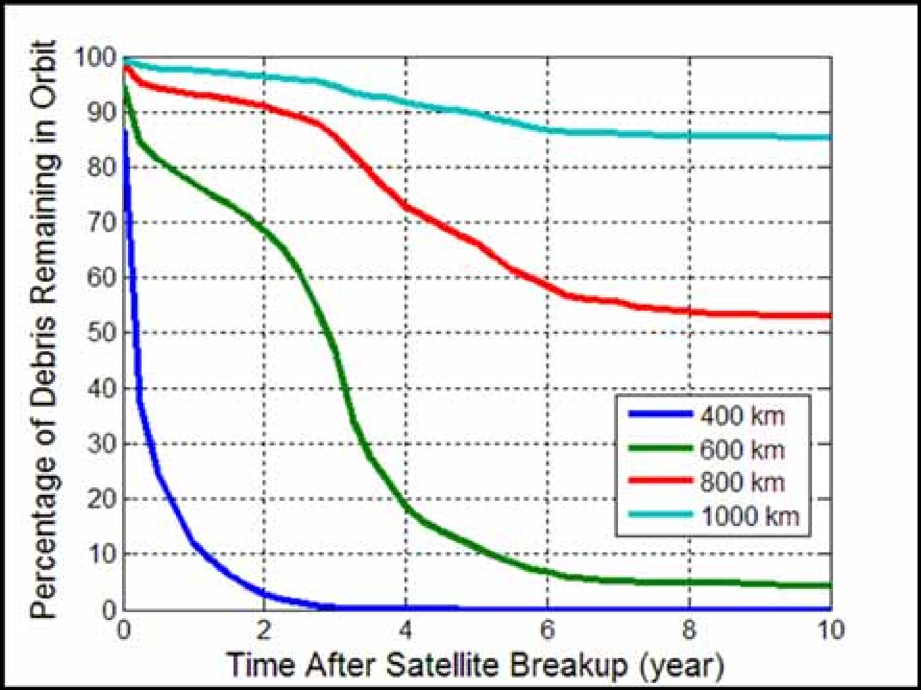
Figure 5: Debris cloud after 3 years.

Includes "J2" and "J4" terms to describe non-sphericity of earth

Collision Debris Lifetime with Altitude



Breakup at solar maximum

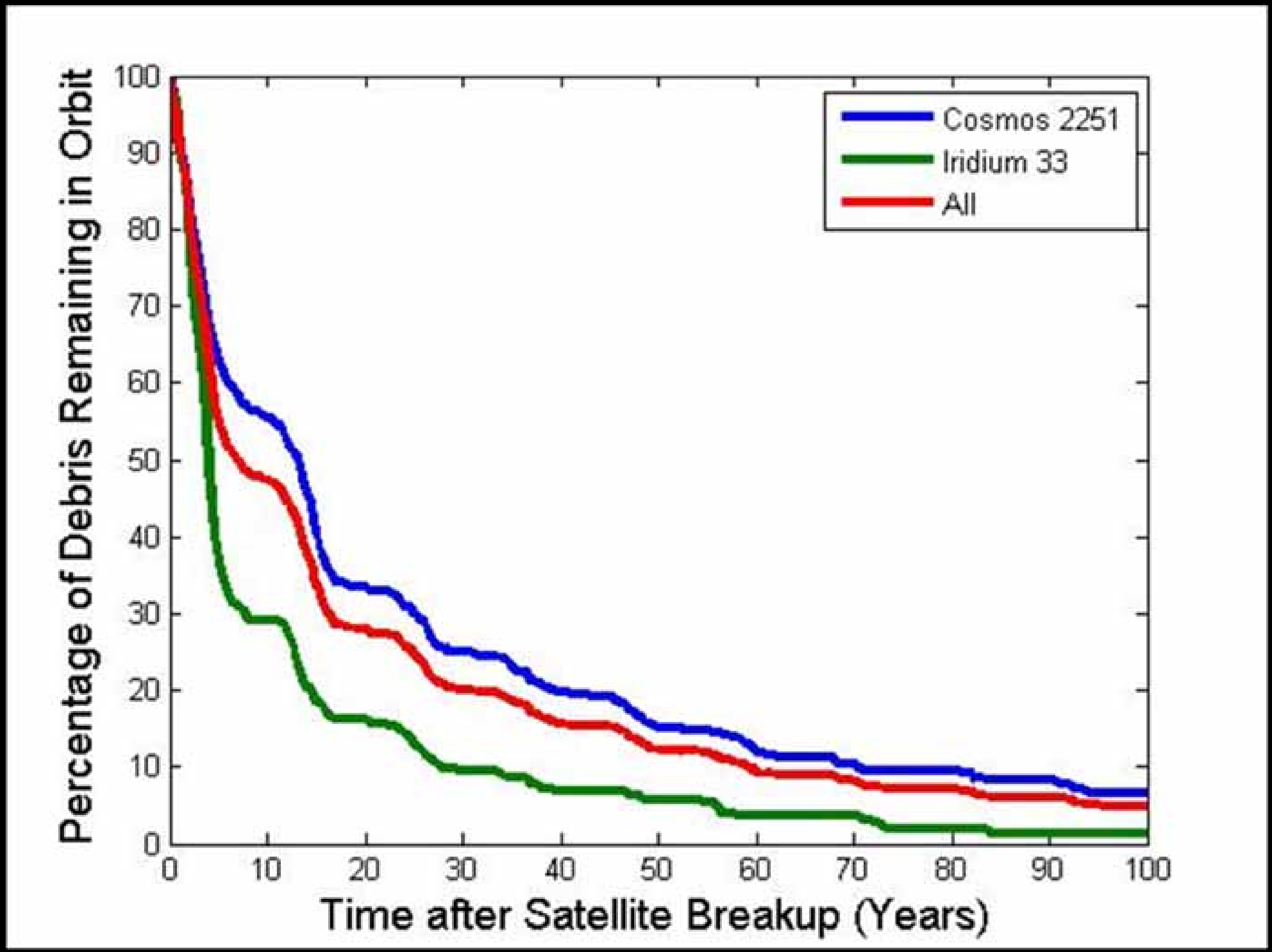


Breakup at solar minimum

For > 10 cm debris from breakup of a 10-ton satellite

Calculation by Wang Ting, BUAA

Estimated Lifetime of Debris from Iridium-Cosmos Collision (790 km)



Calculation by Wang Ting, BUAA

Other Fragmentations

- 18 of the 25 worst (non-deliberate) fragmentations have been rocket bodies (due to residual propellant exploding)
- Strict enforcement of the IADC guidelines should be able to reduce this debris source significantly, but fragmentations continue
- The Briz-M breakup probably could have been avoided by adding a backup system to vent the propellant once there was a propulsion failure
- True for other events as well, including CIS ullage motors
  - 37 have fragmented since 1984 → 250 fragments still in orbit

Known Ullage Motor Breakups

Year	Number of Breakups	Debris Still in Orbit
1960-64	0	0
1965-69	0	0
1970-74	0	0
1975-79	0	0
1980-84	1	0
1985-89	1	6
1990-94	8	21
1995-99	10	19
2000-04	9	57
2005-09	6	>114

This should be solvable by passivation of motors

Delta Second Stage Fragmentations

- 9 stages launched in 1972-8 created 1600 fragments, 909 of which are still in orbit
- 53 Deltas were launched in this period, so 1 in 6 had a fragmenting 2nd stage
- By end of 1977, 6 had fragmented; this should have been a warning
- In 1978, 10 more were launched, and 2 stages fragmented
- Recently, Delta IV and H-IIA 2nd stages have shown odd behavior and should be watched

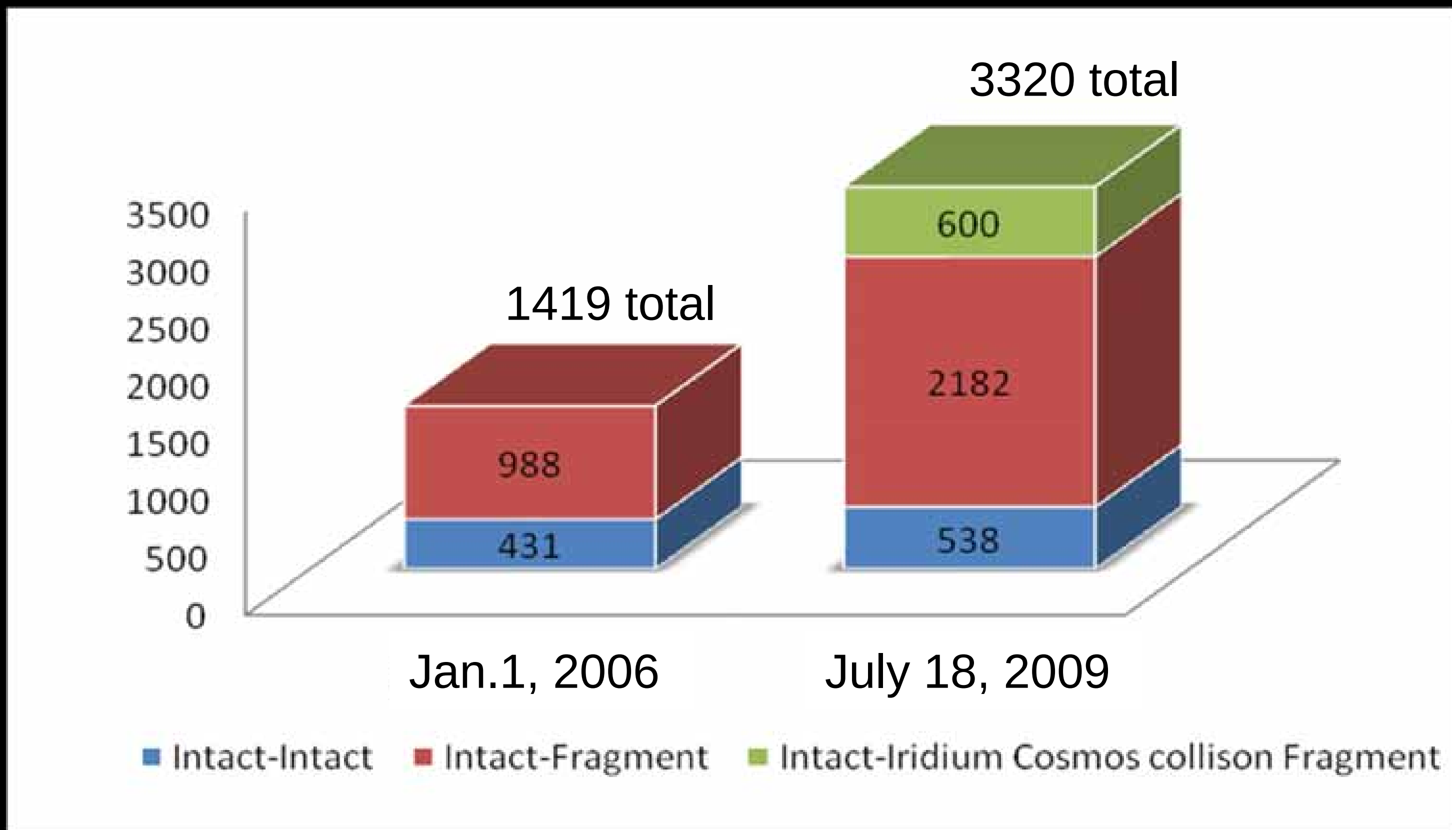
Payloads

- Lifetime of GEO satellites is typcially determined by their fuel, and is predictable, so they can be moved out of GEO orbit
- Lifetime for many LEO satellites is determined by a failure of components, which may not be predictable. So it may not be possible to de-orbit them.
- Many satellites do not have the capability to maneuver.
  - 40% of current active satellites in LEO have not maneuvered in last 2 years, which strongly suggests they are unable to maneuver.
  - These cannot be de-orbited at end of life

Known Cosmos Deliberate Destructions

Year	Number of Destructions	Number of Destructions above 300 km
1960-64	1	0
1965-69	8	7
1970-74	5	5
1975-79	11	11
1980-84	10	10
1985-89	10	6
1990-94	6	1
1995-99	1	0
2000-04	1	0
2005-09	1	0

Collision Risk for LEO Objects Doubled Between 2006-2009



Number of conjunctions (< 5 km) of LEO objects in 24 hour period

Collision risk is proportional to the number of conjunctions.

Calculation by Wang Ting, BUAA

Known Collisions in Orbit

Year	Description
1991	Inactive Cosmos 1934 satellite hit by catalogued debris from Cosmos 296 satellite
1996	Active French Cerise satellite hit by catalogued debris from Ariane rocket stage
1997	Inactive NOAA 7 satellite hit by uncatalogued debris large enough to change its orbit and create additional debris
2002	Inactive Cosmos 539 satellite hit by uncatalogued debris large enough to change its orbit and create additional debris
2005	U.S. rocket body hit by catalogued debris from Chinese rocket stage
2007	Active Meteosat 8 satellite hit by uncatalogued debris large enough to change its orbit
2007	Inactive NASA UARS satellite believed hit by uncatalogued debris large enough to create additional debris
2009	Active Iridium satellite hit by inactive Cosmos 2251

Yellow highlighted events involve active satellites

Underlined events are between two cataloged objects

Debris Threat to Satellites

- **Average time between a collision of debris (> 1 cm) with some active satellite in low earth orbit:**
  - In 2006: 5-6 years
  - Today: 2-3 years

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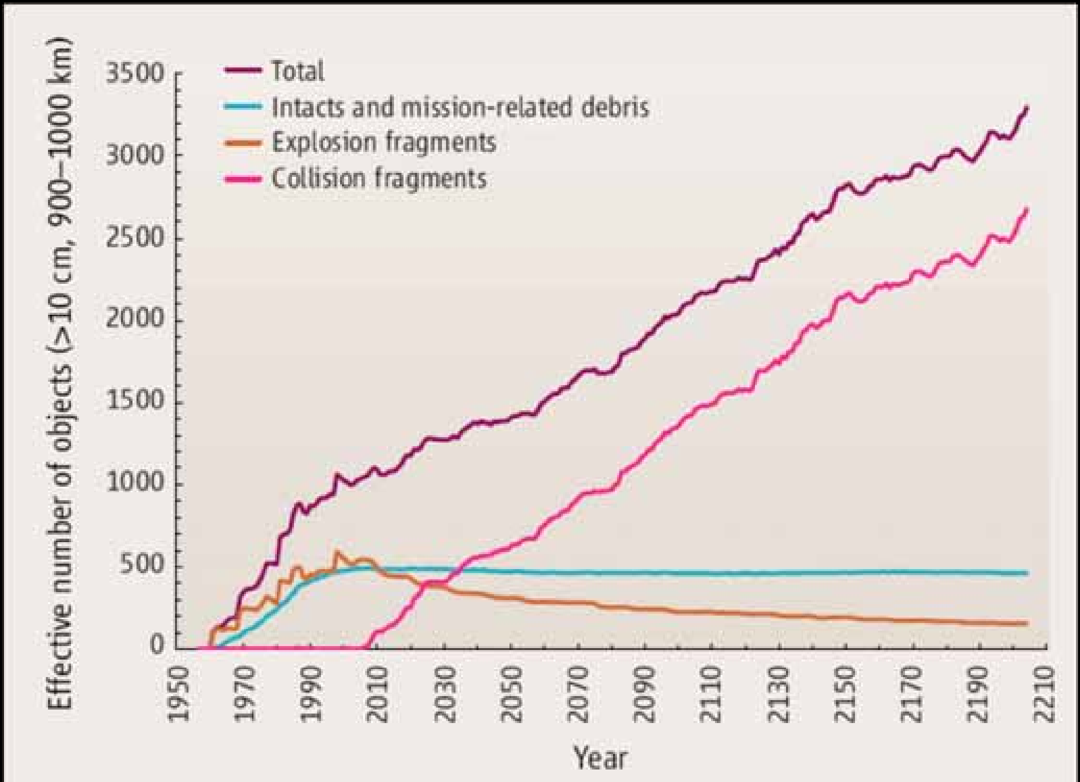
- **In the 800-900 km altitude band, the chance that a satellite will be hit by debris (> 1 cm) is > 1% over the satellite's 5 to 10 year lifetime**

200-year Debris Evolution in 900-1,000 km band

This heavily used altitude band is already in a "super-critical" state:



The red zone. Effective number of objects, 10 cm and larger, between 900- and 1000-km altitudes from the LEGEND simulation.

(Liou-Johnson, *Science*, Jan 2006)

The situation is worse than this for two reasons: (1) there is more debris in this region now than in 2006, (2) NASA's collision probability appears to be too low by a factor of 2-3, based on observed collisions.

Conclusions (1)

- There are mixed signs about how well the mitigation guidelines are working in practice
- There is evidence that standard practices are getting better, especially in the U.S., which is important given its level of space activity
- But years of successful mitigation can be negated by a single large event
- Not doing as well overall as we need to.

Conclusions (2)

- Important to stop deliberate destructions, especially at high altitudes
- Briz-M and other events show the importance of doing better at passivation
- Iridium-Cosmos collision shows the importance of getting defunct objects out of orbit
- It makes little sense to think about active remediation of debris as long as large numbers of new satellites are not being given the ability to de-orbit
  - Lack of political will?